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The hidden nature of parent material in soils of Italian mountain ecosystems

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ABSTRACT

Soils with andic features are known to be very important as regards both ecosystem fertility and susceptibility to land degradation. In recent years there has been an increasing number of finds of these soils in non-volcanic mountain ecosystems (NVME) in different parts of the world under different environmental settings. In Italian NVME there has been extensive investigation proving that these soils have a much wider distribution than previously thought. But despite these important findings, very little is known about their genesis or properties. Against this background, our investigation aims to question the nature of parent material in andic soils in Italian NVME; we consider this question fundamental for proper understanding of such soils. We address the question of the parent material by highlighting similarities/dissimilarities between soils and their underlying bedrocks and ascertaining whether soils developed as a result of in situ weathering or because of eolian inputs. The study was conducted on 41 soil profiles distributed throughout Italian NVME, performing an integrated analysis of (i) grain-size distribution (GSD) by laser granulometry, (ii) end-member modelling of obtained GSD, (iii) soil–bedrock differences in magnetic susceptibility, and (iv) soil–bedrock differences based on the geochemistry of 38 elements. The final results from these investigations show that the investigated soils are mainly derived from eolian sediments and that weathering of the underlying bedrock plays a minor role. Two main types of eolian parent materials seem to coexist in different proportions according to the soil type: eolian sediments with a similar composition of the underlying bedrock (termed autochthonous loess) and eolian sediments of volcanic type (pyroclasts). Autochthonous loess represents the main component of the parent material in the following studied soils: Aluandic Andosols, Cambisols, Phaeozems and Podzol (67%, 63%, 44% and 73%, respectively). All these soils exhibit low to moderate andic features. Volcanic-type eolian sediments constitute about 90% of the parent material in most andic soils that are Silandic Andosols, but occur in different proportions in most of the investigated soils. The nature of soil parent materials surprisingly follows a clear trend with latitude, with autochthonous loess characterizing most parent materials in northern Italy whilst volcanic sediments form most parent materials in the south. In accordance with their latitude, other soils exhibit an intermediate behaviour.

1. Introduction

Soils exhibiting andic features are composed by a very reactive mineral assemblage comprising poorly ordered clay minerals (e.g. allophane, imogolite, ferrihydrite) and Al/Fe-humus complexes (Shoji et al., 1993). They are commonly formed during the weathering of tephra and other parent materials with a significant content of volcanic glass.

Andic soils exhibit very important features, also termed andic properties such as (i) low bulk density (typically <0.90 g/cm^3), (ii) friable structure, (iii) high water retention, (iv) large reserve of easily weatherable minerals, (v) high organic matter content, and (vi) high P retention. Such features account for andic soils having the largest C storage capacity and longest C residence time (Amundson, 2001; Batjes, 1996; Post, 1983) of all mineral soils. Because of their unique chemical, physical and biological properties, andic soils show both very high fertility (Leamy, 1984; Shoji et al., 1993) and very high fragility due to their high susceptibility to land degradation processes (Arnalds, 2000; Arnalds et al., 2001; Basile et al., 2003; Terribile et al., 2007).

In recent years there has been an increasing number of finds of soils with andic properties in non-volcanic mountain ecosystems (NVME) from different parts of the world including Nepal (Baumler and Zech, 1994; Baumler et al., 2005), India (Caner et al., 2000), Austria (Delvaux et al., 2004), North Appalachians (Canada, USA), Kyushu (Japan) and the Alps (Kimble et al., 2000). These soils include different types of parent material and developed under different temperature and water regimes. More recently, Iamarino and Terribile (2008) found andic soils throughout the Italian non-volcanic mountain ecosystems (NVME) in

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sites where the following environmental factors are combined: altitude (>700 m asl), slope gradient (<12°) and active green biomass (max normalised difference vegetation index value >0.5). These soils appear to be rather homogeneous in their morphological, chemical and physical properties (Iamarino, 2005), but interestingly they occur on very different types of parent material, in different temperature and water regimes, and at very different latitudes. These findings are especially important given that Italian mountain ecosystems cover about 35% of the country.

Despite the importance of these soils and their widespread occurrence, very little is known about how, why and when they formed in NVME. However, answering such questions requires investigation of a key preliminary issue: the nature of the parent material of these soils. More specifically, we need to understand whether these soils mainly developed because of weathering in situ of bedrocks or because of eolian inputs. Moreover, if eolian inputs are present, are they generic loess-type sediments or rather volcanic ashes? These questions are not trivial given the importance of both Plinian eruptions and eolian dust transport (like loess type) in the Late Pleistocene and throughout the Holocene in many parts of the world and also in Europe.

This work therefore aims to contribute to a better understanding of the type of parent material occurring in andic soils throughout Italian NVME by comparing analytical signatures between soils and their underlying bedrock (sensu Baize and Jabiol, 1995). We approached this issue by choosing soils on different geological settings and latitudes, and then adopting an integrated multidisciplinary approach including magnetic susceptibility, particle size distribution, soil micromorphology, and geochemistry.

2. The rationale

It is well known that ascertaining the parent material in soils can be a rather complex task (Buol et al., 1989; Fitzpatrick, 1983), simply because in many soils the parent material (or even a relict of it) is no longer in existence. Mineral weathering can dramatically change soil mineralogy and chemistry. Moreover, during their long formation soils might have undergone different phases of pedogenesis resulting in even more complex soil mineral assemblages. The situation is further complicated in the case of andic soils which often develop entirely or partly over volcanic (allochthonous) eolian deposits. In this case, the eolian components with their varying mineralogy and geochemistry can produce an additional difficulty in understanding the soil parent material. In addition, andic soils – because of their variable charge minerals – can have few analytical artefacts (Adamo et al., 1996; Bartoli et al., 1991; Basile and De Mascellis, 1999) which can lead in turn to an unreliable grain-size distribution. It can therefore be concluded that in many soils the understanding of the parent material can be rather difficult and often becomes a matter of inference.

Despite these difficulties, in many instances detailed soil genesis studies, through mineralogical, micromorphological and isotopic signature analysis, have been able to infer the nature of the soil parent material with a good degree of certainty. This is also because such techniques were applied to simplified environmental systems such as specific pieces of landscapes (e.g. toposequences, lithosequences) where a series of parameters (e.g. variability of mineralogy, multiple soil processes occurring at the same time, variability of isotope signatures, environmental setting) are under control.

In our case study, dealing with a large variability of environmental settings and pedons scattered throughout Italian mountain ecosystems, no such detailed analysis could be successfully applied because we were unable to perform a thorough soil genesis study for each of the investigated sites. Thus we attempted to ascertain the soil parent material in andic soils by setting up a novel integrated approach combining the following methods: (i) laser grain-size distribution (GSD) after removal of pedogenetic compounds, (ii) end-member modelling of this "pedogenic free" GSD, (iii) magnetic susceptibility difference between soil fine earth and underlying bedrock, (iv) difference in geochemistry between soil fine earth and the underlying bedrock. Finally we performed, only on selected reference soils, (v) soil micromorphology to detect specific features (e.g. volcanic glass) to be used as a training set for further data processing.

The rationale behind the use of these techniques is based on both the scientific literature and some assumptions. Details on why some of the employed techniques were chosen and employed are given below.

Laser-based GSD has indeed become a standard method in soil and sediment analysis. In the case of soils the GSD curve can be strongly affected by the occurrence of newly soil-forming materials (in the case of andic soils mainly allophane-like materials and Fe oxides) which could act as cementing/flocculating agents changing actual particle size distribution. If the removal of these pedogenetic cementing compounds is obtained, then the GSD curve can produce useful information for inferring the nature of the parent material. Moreover, many advances have been recently performed in GSD processing, especially for detecting the source of sediments in complex multisource alluvial deposits (e.g. Prins and Weltje, 1999a). These advances promise to be profitably applied also to the complexity of the soil material. In the last two decades, magnetic measurements have obtained much credit mainly in sedimentology (Crockford and Fleming, 1998; Thompson et al., 1980) and in some soil science applications (e.g. Feng and Johnson, 1995; Fine et al., 1993; Singer and Fine, 1989) because the technique is non-destructive, inexpensive, fast and fairly informative. In soils, magnetic susceptibility is largely affected by the presence of magnetic forms of iron oxide (e.g. magnetite, maghaemite), which in turn can be produced by few different causes including: (i) occurrence of alternating reduction–oxidation conditions, (ii) burning (hence its archaeological significance), and (iii) microbial activity in topsoils (Clark, 1996; Scollar et al., 1990). In soils where (i), (ii), and (iii) are negligible, magnetic forms of iron oxide and mainly magnetite (a primary mineral difficult to weather) can provide a proxy of soil–bedrock discontinuities. This is the case, for instance, when large differences in soil– bedrock magnetic susceptibility are observed as a consequence of volcanic ash deposition (which are often rich in magnetite) overlying a pre-existing soil or sedimentary bedrock.

Geochemical analysis represents a benchmark method for understanding if a specific soil is derived from the underlying bedrock. It is known that geochemical data must be interpreted with caution given that during soil weathering chemical elements are leached/ accumulated along the soil profile. In case of poorly weathered young soils, the use of geochemical data in addressing soil–bedrock similarity is based on the following assumptions: (a) during weathering the bedrock leaves chemical traces of its contribution to soil genesis; these traces are usually found in the concentration of less mobile elements in the pedosphere, which are less affected by leaching processes in soils; (b) given the geology of Italy (and many other countries in the world), some elements, such as Hf, Zr, U, Th, Nb, La, Ba, and Ce may have a much higher concentration and higher dynamic range in volcanic rocks (Peccerillo, 2005) than in sedimentary rocks (e.g. limestone, sandstone, etc.); (c) comparative soil–bedrock analysis combining both less mobile elements and elements associated with the presence of volcanic rocks can then help understand soil bedrock similarity/dissimilarity.

3. Materials

The study was conducted on 41 soil profiles distributed throughout the Italian NVME (Fig. 1). All soils were collected using as criteria (see Iamarino and Terribile, 2008) altitude (>700 m above sea level), slope (<12°) and active green biomass (maximum normalised difference vegetation index (NDVI) value > 0.5) to identify sites where andic soil processes may occur in the NVME of Italy. Further information on the criteria used are available in Iamarino (2005).